# *On the Properties of Magnetically Shielded Iron as Affected by Temperature.*

By Ernest Wilson.

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In a paper recently read before the Society,* it was shown that if a specimen of stalloy in ring form is placed within an iron shield and then subjected to a magnetic force of about 2 C.G.S. units, its permeability is increased. Moreover, careful demagnetisation was found to increase the permeability at the low forces at the expense of permeability at the higher forces. Further experiments have been made with the same material in ring form at high temperatures. It was thought that if the stalloy, when its temperature passes through the value at which the magnetic quality is regained on cooling, was simultaneously subjected to a magnetising force and shielded from the influence of the earth's magnetism, the permeability might be increased further. This has been found to be the case.

[*Note added May* 7, 1914.—My attention has been called to a paper by Messrs. H. Pender and R. L. Jones on "The Annealing of Steel in an Alternating Magnetic Field." These authors have obtained high values of the permeability (see the 'Physical Review,' 2nd Series, April, 1913, vol. 1, No. 4).]

In an earlier paper† experiments were described in connection with two small stalloy rings which have been used in the present experiments.

In Table I the present experiments are numbered in the order in which they were made, and the curves are numbered in correspondence with them.

### *Ring No.* 1.

The specimen, which had been heated several times above the temperature at which magnetic quality is lost, was wound with an asbestos-covered wire and placed in a small iron box, the whole being heated in a gas furnace to the neighbourhood of 800° C. About two hours were required to heat the specimen. It was allowed to cool inside the magnetic shield previously used and described (*loc. cit.*), and at the same time it was subjected to a steady magnetising force of 3·12 C.G.S. units. About five hours were required to cool it to atmospheric temperature. When at atmospheric temperature the specimen was taken out and tested for magnetic permeability. The figures were obtained whilst gradually reducing the force and are given in Table I,

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* 'Roy. Soc. Proc.,' A, vol. 90, p. 179 (1914).

† 'Phys. Soc. Proc.,' vol. 23, Part 4, p. 253, June 15, 1911.

## Table I.—Permeability.

| | Ring No. 1. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Expt. …… | 1. | | 2. | | 3. | | 4. | |
| $H_{\text{max}}$. | Just after being taken out of furnace. | | After being re-wound. | | After demagnetisation from H = 4·17. | | After being polarised at H = 6·16 and subjected to vibrations. | |
| | B. | $\mu$. | B. | $\mu$. | B. | $\mu$. | B. | $\mu$. |
| 0·0105 | | | 2·67 | 254 | 4·81 | 457 | 3·29 | 312 |
| 0·0209 | | | 6·15 | 294 | 11·8 | 563 | 7·89 | 378 |
| 0·0522 | | | 23 | 441 | 42·8 | 820 | 34·2 | 655 |
| 0·105 | | | 63·6 | 606 | 116 | 1106 | 103 | 982 |
| 0·223 | | | 209 | 935 | 369 | 1655 | 365 | 1640 |
| 0·311 | 314 | 1060 | 397 | 1275 | 727 | 2346 | 748 | 2400 |
| 0·366 | 2072 | 5630 | | | 1150 | 3150 | 1210 | 3310 |
| 0·418 | | | | | 1870 | 4470 | 1920 | 4600 |
| 0·471 | 4030 | 8900 | 3892 | 7660 | 2710 | 5750 | 2750 | 5850 |
| 0·570 | 5910 | 10140 | | | 4280 | 7510 | 4360 | 7640 |
| 0·617 | | | 5140 | 8330 | 4840 | 7840 | 4920 | 7980 |
| 0·726 | | | | | 5906 | 8140 | 6040 | 8320 |
| 0·830 | 7530 | 9370 | 6860 | 8270 | 6665 | 8020 | 6780 | 8170 |
| 0·988 | | | 7590 | 7680 | 7540 | 7640 | | |
| 1·16 | 8970 | 7190 | 8160 | 7030 | 8100 | 6980 | 8200 | 7070 |
| 1·39 | | | 8780 | 6500 | 8700 | 6280 | 9300 | 5920 |
| 2·41 | 10200 | 4720 | 10030 | 4300 | 9960 | 4130 | 9880 | 4870 |
| 3·81 | 10500 | 3430 | 10560 | 2930 | 10660 | 2800 | 10460 | 3780 |
| 6·16 | | | 11100 | 1950 | 11200 | 1820 | 11050 | 2480 |
| 12 | | | | | | | 11940 | 995 |
| 31·4 | | | | | | | 12800 | 408 |
| 45·6 | | | | | | | 13200 | 290 |

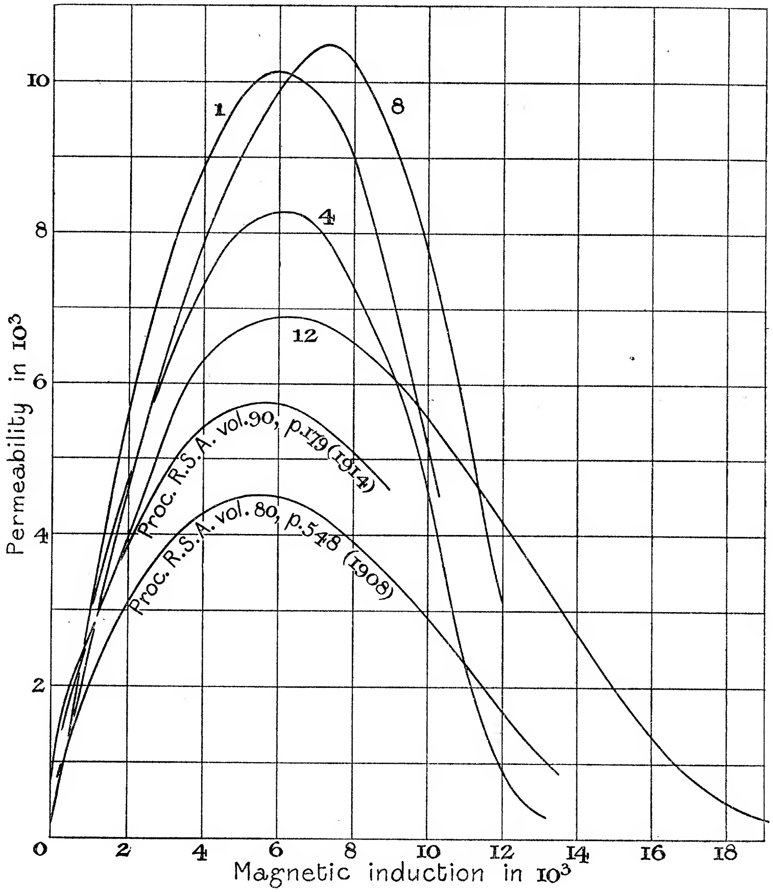
| | Ring No. 3. | | | |
|---|---|---|---|---|
| Expt. …… | 11. | | 12. | |
| $H_{\text{max}}$. | After polarisation to H = 174 in shield. | | Demagnetised from H = 2 and resting all night. | |
| | B. | $\mu$. | B. | $\mu$. |
| 0·00343 | 0·994 | 292 | 1·45 | 422 |
| 0·00687 | 2·01 | 293 | 2·98 | 435 |
| 0·0115 | 3·53 | 307 | 5·33 | 464 |
| 0·0228 | 7·96 | 349 | 12·1 | 531 |
| 0·0571 | 25·4 | 444 | 48·1 | 843 |
| 0·115 | 65·9 | 573 | 139·6 | 1214 |
| 0·243 | 218 | 898 | 482 | 1984 |
| 0·394 | 459 | 1170 | 964 | 2450 |
| 0·674 | 4280 | 6350 | 3250 | 5690 |
| 0·800 | 5430 | 6790 | 5440 | 6800 |
| 0·915 | 6320 | 6900 | 6320 | 6900 |
| 1·03 | 7060 | 6860 | 7010 | 6800 |
| 1·25 | | | 7600 | 6700 |
| 1·16 | 7920 | 6710 | | |
| 1·34 | 8700 | 6350 | 8370 | 6410 |
| 1·76 | | | 9990 | 5660 |
| 3·12 | | | 12250 | 3930 |
| 4·66 | | | 13650 | 2930 |
| 5·54 | | | 14300 | 2580 |
| 9·79 | | | 15500 | 1580 |
| 10·45 | | | 15850 | 1520 |
| 17·42 | | | 16800 | 965 |
| 38·54 | | | 17970 | 466 |
| 50·4 | | | 18540 | 368 |
| 77·7 | | | 19300 | 248 |
| 119·5 | | | 20340 | 170 |

Table I.—*continued.*

| Ring No. 2. | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Expt. …… | 5. | | 6. | | 7. | | 8. | | 9. | | 10. | |
| Hmax. | Before heat treatment. | | After annealing in shield without magnetising force. | | After demagnetisation from H = 32 at 50 frequency. | | Just after being taken out of furnace. | | After re-winding but otherwise not treated. | | After demagnetisation from H = 8·95. | |
| | B. | μ. | B. | μ. | B. | μ. | B. | μ. | B. | μ. | B. | μ. |
| 0·00683 | | | | | | | | | 1·72 | 252 | 2·87 | 420 |
| | 3·95 | 376 | 3·2 | 306 | 2·96 | 282 | | | | | | |
| 0·0139 | | | | | | | | | 3·39 | 283 | 5·75 | 414 |
| | 9·8 | 471 | 6·91 | 332 | 6·66 | 321 | | | | | | |
| 0·0275 | | | | | | | | | 8·62 | 313 | 15·5 | 564 |
| | 35·5 | 683 | 25·8 | 496 | 27·4 | 527 | | | | | | |
| 0·0689 | | | | | | | 11·4 | 194 | 34·5 | 501 | 58 | 842 |
| | 93·3 | 905 | 71·1 | 690 | 82 | 796 | | | | | | |
| 0·129 | | | | | | | | | 88·6 | 688 | 151 | 1173 |
| 0·138 | | | | | | | | | 98·6 | 715 | 160 | 1160 |
| | 277 | 1250 | 218 | 1000 | 261 | 1200 | 45·8 | 281 | | | | |
| 0·2935 | | | | | | | | | 366 | 1250 | 605 | 2060 |
| | | | 364 | 1170 | 503 | 1610 | 158 | 501 | | | | |
| 0·345 | | | | | | | *786 | 2490 | 817 | 2370 | 853 | 2470 |
| 0·414 | | | | | | | | | 1330 | 3210 | 1475 | 3560 |
| | | | | | | | 2150 | 4910 | | | | |
| 0·483 | | | | | | | | | 2450 | 5070 | 2350 | 4870 |
| 0·552 | | | | | | | 4520 | 8510 | 3350 | 6060 | 3390 | 6140 |
| | 2610 | 4250 | 1220 | 1980 | 2390 | 3890 | | | | | | |
| 0·621 | | | | | | | 6020 | 9540 | 4090 | 6580 | 4150 | 6610 |
| | | | 3180 | 4400 | 3300 | 4570 | | | | | | |
| 0·759 | | | | | | | 7390 | 10480 | 5490 | 7230 | 5470 | 7210 |
| 0·814 | | | | | | | 8090 | 10200 | 5920 | 7270 | 5870 | 7210 |
| | | | 4010 | 4800 | 4080 | 4880 | | | | | | |
| 0·966 | | | | | | | | | 6780 | 7020 | 6720 | 6960 |
| | | | 5140 | 4940 | 5150 | 4850 | | | | | | |
| 1·10 | 5820 | 5020 | 5670 | 4850 | | | 9340 | 8810 | 7370 | 6700 | 7340 | 6670 |
| | 6070 | 5100 | 5950 | 4800 | 5650 | 4830 | 9660 | 8400 | | | | |
| 1·31 | | | | | | | 10300 | 7620 | 8030 | 6130 | 8110 | 6190 |
| 1·54 | | | | | | | 10440 | 6910 | 8610 | 5590 | 8680 | 5640 |
| | | | | | | | | | | | 9430 | 5300 |
| 2·04 | | | | | | | 10880 | 5750 | 9790 | 4800 | 9660 | 4800 |
| | 8750 | 3420 | 8160 | 3780 | 8160 | 3670 | 11040 | 4990 | | | | |
| 2·65 | | | | | | | | | 10360 | 3910 | 10330 | 3900 |
| | | | 8720 | 3320 | | | | | | | | |
| 3·38 | | | | | | | 11800 | 3420 | 10850 | 3210 | 10700 | 3170 |
| | 9850 | 2480 | | | 9900 | 2520 | | | | | | |
| 4·31 | | | | | | | | | | | 11200 | 2600 |
| 5·85 | 10900 | 1860 | | | | | | | | | | |

* Obtained after the force had been put back from 0·438 to 0·315.

Experiment 1, and plotted in Curve 1. In all the other experiments the force has been increased gradually. It will be seen that the permeability rises to about 10,000. The ring was then stripped and re-wound with cotton-covered primary and secondary windings, the secondary winding being next to the stampings, and this operation gave rise to considerable mechanical disturbance. Experiment 2 shows that the maximum permeability has dropped to 8330, and the initial permeability is small. On demagnetising the specimen (Experiment 3) the effect previously observed is produced, namely, the initial permeability is increased and the maximum reduced. On again polarising the specimen with a force of 6·16 and leaving it for four days the ring was subjected for about half an hour to a high alternating force having a maximum of 24 C.G.S. units at 80 complete periods per second. This caused the plates to vibrate and give the characteristic sound. After an interval of two days Experiment 4 was then made. It



will be seen that the maximum permeability went up to 8320, and that the initial value was lower than in Experiment 3. Experiment 4 also includes the taking of a few hysteresis loops, the particulars of which are given in Table II. In the same table are also given figures taken from a normal specimen of stalloy which had been demagnetised most carefully.* The maximum values of the magnetic induction happen to be very nearly the same. It will be noticed that the coercive force $H_0$ in the present experiments is smaller for this value of the induction, whereas the residual magnetism $B_0$ is larger. The ergs per cycle per cubic centimetre are less in the ratio 705/1030.

Table II.—Hysteresis.

| Expt. | Hmax. | Bmax. | Permeability, $\mu$. | Ergs per cycle per cubic cm. | Coercive force, $H_0$. | Residual magnetism, $B_0$. |
|---|---|---|---|---|---|---|
| 4 | 0·223 | 369 | 1655 | 5·53 | 0·0646 | 116 |
| | 0·471 | 2800 | 5940 | 215 | 0·306 | 2100 |
| | 0·726 | 6040 | 8320 | 705 | 0·404 | 5150 |
| | 2·77 | 10460 | 3780 | 1750 | 0·488 | 9020 |
| 'Roy. Soc. Proc.,' A, vol. 80, p. 548 (1908) | 1·354 | 6050 | 4470 | 1030 | 0·60 | 4666 |

## *Ring No.* 2.

This specimen had been cooled several times to the temperature of liquid air, and it was mentioned in the earlier paper† that such treatment had the effect of increasing permeability when in a demagnetised condition. It has behaved somewhat differently from Ring No. 1, that is to say, when the specimen has been polarised in the shield the maximum permeability has not suffered so marked a change as might have been expected from the earlier experiments. After a preliminary test (Experiment 5), as it was originally left after the cooling experiments, the ring was divested of its winding and raised to a temperature of about 800° C. It was then allowed to cool in the shield without any applied magnetic force. On re-winding it the permeability was found to be slightly smaller (Experiment 6). The ring was then wound with an asbestos-covered coil and allowed to cool from about 800° C. in the shield, with a steady force of 14 C.G.S. applied constantly. Experiment 8 was then made. As in the case of Ring No. 1, a maximum permeability of over 10,000 was obtained, and it is larger than in the case of Ring No. 1, for the higher values of the magnetic induction. Curve 8 can be compared with Curve 1 in this connection. The specimen was then re-wound and Experiment 9 made. The effect of mechanical disturbance has again been to lower the maximum permeability, but in this case to 7230, as against 8330 in the case of Ring No. 1. After demagnetising the specimen from a force of 8·95 C.G.S. units Experiment 10 was made. It will be seen that, although the permeability at low forces is increased, the maximum value is not diminished, as might have been expected.

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* 'Roy. Soc. Proc.,' A, vol. 80, p. 548 (1908).

† 'Phys. Soc. Proc.,' vol. 23, Part 4, p. 256, June 15, 1911.

In each of the above cases no allowance has been made for slight possible burning away of magnetisable material.

### *Ring No.* 3.

In order to compare the results above described with those obtained by treatment in the shield without heating, another specimen of stalloy was chosen and as the polarising forces used in the original paper were small, it was thought well to try the effect of a larger one. Ring No. 3 was polarised to a force of 174 C.G.S. units in the shield, and Experiment 11 was then made. The maximum permeability in this specimen has the value 6900 as against 5900 in the earlier experiments. Demagnetising the specimen from $H = 2$ C.G.S. units has increased the permeability at the lower forces but not seriously affected its maximum value. Curve 12 is interesting, as it shows that the moderate maximum permeability of 6900 gives rise to higher permeabilities at the larger values of the magnetic induction.

### *Electric Resistance.*

An experiment has been made to discover whether the specific resistance of stalloy is affected when it has been subjected to cold treatment in the shield, and has yielded a negative result.

### *Conclusion.*

The experiments show that the permeability of stalloy in ring form can be increased greatly by heat treatment, that is by allowing the material to cool through the temperature at which it becomes a magnetisable substance during the time that it is shielded from the influence of the earth's magnetism and subjected to a magnetising force. Values of the permeability higher than 10,000 have been obtained. A characteristic feature of the curve of permeability and magnetic induction is that the higher the maximum permeability the lower is the permeability at the higher values of the induction. The dissipation of energy due to magnetic hysteresis is lower than in the normal stalloy specimen for a given value of the magnetic induction.

The above experiments were made in the Sir William Siemens Electrical Engineering Laboratory, University of London, King's College. I wish to thank my laboratory attendant, Mr. George Jones, for the assistance which he rendered.

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# *On Newcomb's Method of Investigating Periodicities and its Application to Brückner's Weather Cycle.*

By Prof. ARTHUR SCHUSTER, Sec. R.S

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During the last few years of his life Prof. Simon Newcomb was keenly interested in the problem of periodicities, and devised a new method for their investigation. This method is explained, and to some extent applied, in a paper entitled "A Search for Fluctuations in the Sun's Thermal Radiation through their Influence on Terrestrial Temperature." The importance of the question justifies a critical examination of the relationship of the older methods to that of Newcomb, and though I do not agree with his contention that his process gives us more than can be obtained from Fourier's analysis, it has the advantage of great simplicity in its numerical work, and should prove useful in a certain, though I am afraid, very limited field.

Let $f(t)$ represent a function of a variable which we may take to be the time, and let the average value of the function be zero. Newcomb examines the sum of the series

$$f(t_1)f(t_1+\tau)+f(t_2)f(t_2+\tau)+f(t_3)f(t_3+\tau)+\ldots,$$

where $t_1$, $t_2$, etc., are definite values of the variable which are taken to lie at equal distances from each other. If the function be periodic so as to repeat itself after an interval $\tau$, the products are all squares and each term is positive. If, on the other hand, the periodic time be $2\tau$, each product will be negative and the sum itself therefore negative. It is easy to see that if $\tau$ be varied continuously the sum of the series passes through maxima and minima, and the maxima will indicate the periodic time, or any of its multiples.